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Optimising growing environment and cultivar in rainfed pearl millet (*Pennisetum glaucum*) cultivation for higher growth and productivity

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India and Africa together generate 93.2% of the world's pearl millet (*Pennisetum glaucum* L.) crop. It is the fifth most important grain crop after rice, wheat, maize and sorghum in India. Grown in dry and semi-arid regions, it makes up 10.7% of the country's total food grain production (Ramniwas *et al.* 2023). India led the world in agricultural production with 6.55 mha under cultivation and an annual yield of 9.64 Mt (DES 2026). In terms of non-monetary inputs determining crop output, sowing timing is the most significant. By creating a favourable environment for all growth phases, sowing at the ideal time increases productivity. Upadhyay *et al.* (2001) through the study reported that summer pearl millet yield more when sown on March 15th, and also observed that the grain yield decreases with later sowing. Agro-climatic variables, crop growth season and variety, all affect the sowing time. The reason for this is that ideal seeding dates create robust, healthy plants, which is why planting dates are crucial for optimising cereal grain production (Zhang *et al.* 2022). For a broad range of climatic conditions, delayed seeding is linked to a considerable drop in grain output (Wang *et al.* 2025). It was observed by Samarah *et al.* (2023) that an ideal temperature could help explain variations in the development of cereals sown at various dates. Thus, the objective of the present study was to assess the impact of cultivars and crop growth environments on crop growth indices, yield and yield attributes of pearl millet cultivated under Eastern Plain Zones of Uttar Pradesh.

During the 2023 rainy (*kharif*) season, the experiment was set up at the Agro-meteorological Research Farm of Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya (26.472°N, 82.122°E; at an elevation of 113 m amsl), Uttar Pradesh. The experiment was laid out in a factorial randomised block design (F-RBD). Nine treatment combinations comprised of three sowing dates, viz. crop sown on 28th June, 8th July and 18th July, respectively along with three varieties i.e. PC-701, HHB-67 and RHB-223 were used in the investigation. Observations like crop growth indices, plant population, yield attributes and yield were recorded during crop production on five randomly chosen tagged plants from each individual plot of the experimental field. The leaf area index (LAI) was calculated using the formula:

$$\text{LAI} = [\text{Leaf area (cm}^2\text{)/Ground area (cm}^2\text{)}]$$

To measure plant height (cm) and mean panicle length (cm) at different intervals, five randomly chosen tagged plants from each plot were chosen. The quantity of tillers/plant that generated grain-filled panicles was measured as the effective number of tillers/plant as yield attribute. A vernier calliper or measuring tape was used to measure the panicle's thickness (cm) to determine its girth. At harvest, the length of each earhead, thickness of each earhead at the centre and average earhead girth was measured from the five randomly chosen plants in each net plot. During harvest, the average grain weight/earhead was measured by taking the weight of all the earheads from the tagged plants. Spoilage yield was calculated by removing the seed yield from the total amount of output on a net plot. Relative to net plot area, stump yield was measured in kg and was represented as q/ha. After reaching maturity, each plot's ground components were harvested and the weighted results were presented in t/ha, representing the biological yield. Harvest index (HI) was calculated as:

$$\text{HI (\%)} = [\text{Grain yield (t/ha)}]/[\text{Biological yield (t/ha)}] \times 100$$

Statistical analysis: Analysis of variance (ANOVA), at 5% significance level was used to compute the critical difference (CD) values, indicating non-significant differences in treatment.

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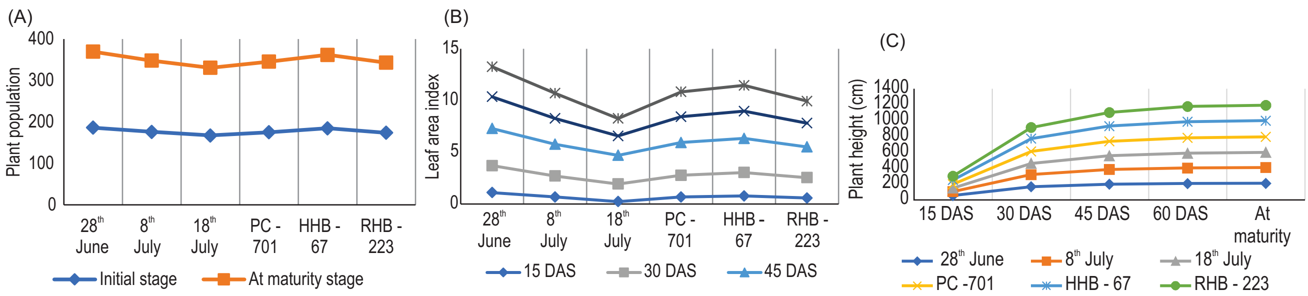

Fig. 1 Effect of crop growing environments and cultivars on (A) Plant population, (B) Leaf area index and (C) Plant height of pearl millet.
DAS, Days after sowing.

Plant population: Plant population at 15 days after sowing (DAS) and physiological maturity varied significantly among environments. Sowing on 28^{th} June recorded the highest plant stand due to better germination and survival, whereas 8^{th} July and 18^{th} July sowings showed 11.1% and 6.8% lower plant population, respectively (Fig. 1A). Among varieties, HHB-67 maintained the highest plant population (184.9), followed by PC-701 (175.3) and RHB-223 (174.0), both at 15 DAS and maturity (Fig. 1A).

The superior plant population under 28^{th} June sowing indicated congenial soil moisture and temperature, favouring germination and establishment while delayed sowings suffered higher mortality, consistent with earlier reports of Rani *et al.* (2018) and Singh *et al.* (2020) in pearl millet. Genotypic differences further revealed that HHB-67 sustained better plant stand across environments, reflecting its vigour and adaptability, which is crucial for maintaining yield potential (Yadav *et al.* 2019). The present findings thus reinforce that timely sowing with a stable genotype like HHB-67 ensures optimum crop stand and productivity.

Leaf area index (LAI): It was significantly influenced by sowing environment, except at 15 DAS and physiological maturity. LAI increased progressively until 45 DAS and declined thereafter. The crop sown on 28^{th} June recorded the maximum LAI (3.60) at 45 DAS, which was 17% and 30% higher than 8^{th} July (3.07) and 18^{th} July (2.77), respectively (Fig 1B). Among genotypes, HHB-67 attained the highest LAI (3.30) at 45 DAS, followed by PC-701 (3.17) and RHB-223 (2.97). At early crop stages (15–30 DAS), 28^{th} June sowing showed 37% and 92% higher LAI over 8^{th} and 18^{th} July environments (Fig. 1B). The greater LAI under 28^{th} June sowing suggested congenial soil moisture and thermal conditions that promoted rapid leaf expansion, higher radiation interception and photosynthetic efficiency, while delayed sowings restricted canopy growth (Kumar *et al.* 2012, Patel *et al.* 2017). Variation among genotypes showed HHB-67's superiority in sustaining higher LAI, reflecting its vigour and adaptability, which is critical for biomass production and grain yield in pearl millet (Basu *et al.* 2010, Rai *et al.* 2014). These results corroborate earlier findings that optimum sowing time and genotype selection are crucial for achieving desirable canopy architecture and productivity.

Plant height: Plant height increased progressively with crop growth across environments. At physiological maturity, the tallest plants were recorded under 28^{th} June sowing (208.9 cm) followed by 8^{th} July (199.1 cm) and 18^{th} July (190.4 cm) (Fig. 1C). HHB-67 maintained superior early vigour, being 24% and 8.7% taller than RHB-223 and PC-701, respectively at 15 DAS. Although RHB-223 lagged behind up to 45 DAS, all varieties showed rapid height increase thereafter. At crop maturity, HHB-67 (204.19 cm) remained taller than PC-701 (195.89 cm) and RHB-223 (192.42 cm) (Fig. 1C). The greater height in 28^{th} June sowing indicated congenial conditions for vegetative growth, whereas delayed sowings reduced plant stature due to shortened growth duration and sub-optimal environment, consistent with earlier findings in pearl millet (AICPMIP 2015). Genotypic variation showed HHB-67's superiority, reflecting its vigour and adaptability, while RHB-223 remained relatively shorter, similar to reports of differential growth habit among hybrids (Vadez *et al.* 2012). Since plant height strongly influences canopy structure, radiation capture and biomass accumulation, its optimisation through timely sowing and hybrid choice is crucial for yield stability.

Total number of tillers/plant: The number of tillers/plant was significantly influenced by environments and cultivars. Maximum tillers were recorded under 28^{th} June sowing (4.33) followed by 8^{th} July (3.67), while the lowest were observed in RHB-223 (2.80) (Fig. 2A). Among cultivars, HHB-67 produced the highest number of tillers (3.83) followed by PC-701 (3.67) and RHB-223 (3.30) (Fig. 2A). Higher tiller production in the 28^{th} June sowing indicated favourable conditions for early establishment and vegetative growth, while delayed sowings reduced tillering due to shortened growth duration and stress exposure, in agreement with earlier findings (Patel *et al.* 2017). Genotypic variation also revealed that HHB-67 maintained superiority in tillering ability, reflecting its vigour and adaptability, which directly contributes to higher sink capacity and yield potential in pearl millet (Rai *et al.* 2014). The present results confirmed that timely sowing and selection of high-tillering hybrids like HHB-67 enhance productivity.

Total dry matter accumulation: Dry matter accumulation (DMA) increased progressively with crop age up to physiological maturity. Among environments, maximum

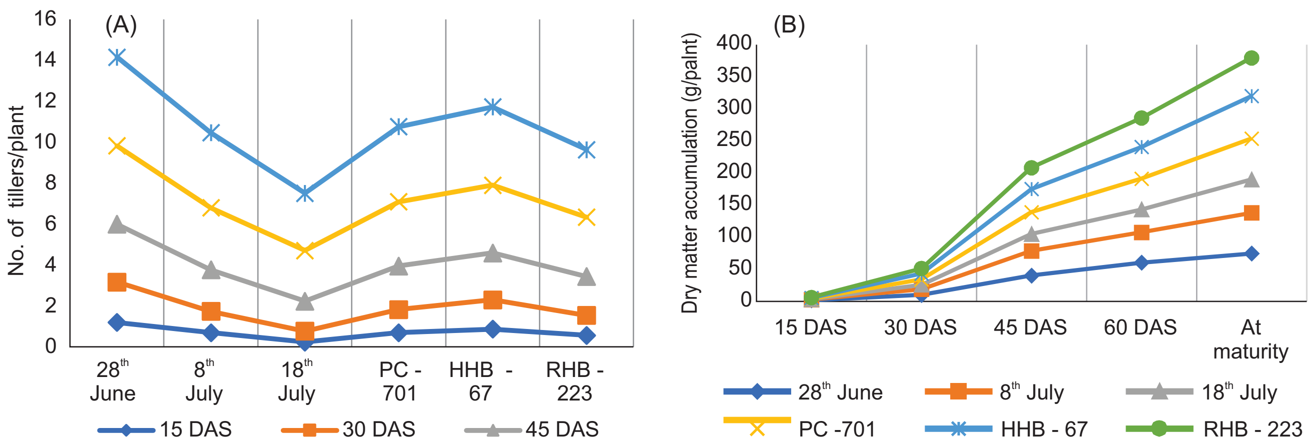

Fig. 2 Effect of crop growing environments and cultivars on (A) No. of tillers/plant and (B) Dry matter accumulation (g/plant) in pearl millet.
DAS, Days after sowing.

total DMA was observed in 28th June sowing (1.5–74.3 g/plant) followed by 8th July, while the lowest was in 18th July (0.5–52.1 g/plant) (Fig. 2B). Across cultivars, HHB-67 accumulated the highest dry matter (1.2–66.2 g/plant), whereas PC-701 (0.9–56.4 g/plant) and RHB-223 (0.8–59.8 g/plant) showed lower biomass production, with RHB-223 consistently lagging at all growth stages (Fig. 2B). Higher DMA under 28th June sowing suggested congenial thermal and moisture conditions that enhanced canopy development, photosynthesis and assimilate partitioning, while delayed sowing restricted biomass build-up due to shortened growth duration (Singh *et al.* 2020). These findings corroborate earlier reports that timely sowing and selection of high-vigour hybrids like HHB-67 ensure optimum dry matter production and productivity in pearl millet.

Yield attributes: Yield attributes were significantly influenced by sowing environment and cultivars. The 28th June sowing recorded the highest panicle length (25.9 cm), panicle girth (9.6 cm), panicle weight (19.2 g), and test weight (8.67 g), followed by 8th July and 18th July sowings (Table 1). Among cultivars, HHB-67 showed superiority with maximum panicle length (25.8 cm), panicle weight (19.7 g), and test weight (8.01 g), followed by PC-701 (24.3 cm, 18.2 g, 7.65 g) and RHB-223 (22.4 cm, 17.4 g, 7.46 g), respectively (Table 1). The superiority of yield attributes in the 28th June sowing reflects favourable early-season conditions that enhanced assimilate partitioning to the reproductive organs, whereas delayed sowings reduced ear development and seed filling, similar to earlier reports (Patel *et al.* 2017). Genotypic variation showed HHB-67's consistent advantage in panicle size, panicle weight and test weight, indicating its high sink strength and adaptability under varying environments (Yadav *et al.* 2019). The present findings confirm that timely sowing coupled with high-yielding hybrids like HHB-67 can maximise yield potential in pearl millet.

Table 1 Effect of crop growing environments and cultivars on yield attributes and yields in pearl millet

Treatments	Length of panicle (cm)	Girth of panicle (cm)	Weight of panicle (g)	Test weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	Biological (t/ha)	Harvest index (%)
Crop growing environments								
28th June (33.2°C)	25.9	9.60	19.2	8.67	4.53	14.0	19.5	23.2
8th July (31.8°C)	24.2	8.70	18.5	7.50	3.26	11.0	14.9	21.8
18th July (34.8°C)	22.3	7.20	17.1	6.97	2.47	9.91	12.3	19.9
SEM	1.10	0.61	0.71	0.30	0.21	0.97	1.0	0.22
CD (p=0.05)	3.29	1.75	2.0	0.87	0.63	2.93	3.0	0.68
Cultivars								
PC-701	24.3	8.47	18.2	7.65	3.57	11.7	15.7	22.7
HHB-67	25.8	8.90	19.7	8.01	4.22	12.4	16.9	24.9
RHB-223	22.4	8.17	17.4	7.46	3.30	10.8	14.2	23.7
SEM	1.0	0.45	0.71	0.52	0.13	0.30	0.80	0.25
CD (p=0.05)	3.0	NS	2.0	NS	0.40	0.90	2.30	0.70

NS, Non-significant.

Yield: Grain, straw and biological yields, along with harvest index, were significantly influenced by sowing environment and cultivars. The highest grain yield was obtained from the sowing done on 28th June (4.53 t/ha), followed by 8th July (3.26 t/ha) and 18th July (2.47 t/ha). Similarly, straw yield (14.0 t/ha), biological yield (19.5 t/ha) and harvest index (23.2%) were also maximum on 28th June (Table 1). Among cultivars, HHB-67 recorded the highest grain yield (4.22 t/ha), straw yield (12.4 t/ha), biological yield (16.9 t/ha) and harvest index (24.9%), followed by PC-701 and RHB-223 (Table 1). The superiority of yields under 28th June sowing highlights the importance of timely planting, which ensured favourable conditions for vegetative growth and effective assimilate partitioning, whereas delayed sowing reduced productivity due to shortened growth period and stress exposure (Singh *et al.* 2020). The present findings confirm that timely sowing coupled with high-yielding hybrids like HHB-67 maximises both biomass and grain productivity.

SUMMARY

The present experiment conducted at Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya, Uttar Pradesh during *kharif* season of 2023 revealed that the early sowing yielded significantly enhanced the plant height, dry matter accumulation (DMA), leaf area index (LAI) and grain yield by 10%, 42.6%, 70.5% and 83.4%, respectively over 18th July. Among different cultivars, HHB-67 surpassed the rest of the varieties. This variety improved the plant height, DMA, LAI, grain yield by 6.25%, 10.8%, 19% and 24.8%, respectively over RHB-233. Therefore, HHB-67 with sowing time of 28th June could be recommended for Kumarganj region of Uttar Pradesh especially under rainfed situations.

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